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(71) Applicant  
Rolls-Royce plc

(Incorporated in the United Kingdom)

65 Buckingham Gate, London, SW1E 6AT,  
United Kingdom

(72) Inventors  
Philip John Doorbar  
Ian David Andrew Sudds

(74) Agent and/or Address for Service  
M.A. Gunn  
Patents Department, Rolls-Royce Plc, P.O. Box 31,  
Moor Lane, Derby, DE2 8BJ, United Kingdom

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## (54) A method of making a fibre reinforced metal component

(57) A ceramic fibre reinforced metal rotor (10) with integral rotor blades 16 is manufactured starting with a continuous strip of unidirectional ceramic fibres in a metal matrix. The continuous strip is cut into a plurality of separate pieces 20 of predetermined length which are arranged alternately in a spiral, with separate pieces of unreinforced metal matrix 22 in adjacent abutting relationship to form a ring which has a plurality of laminations 26. The ring of laminations 26 is arranged between an inner and an outer metal ring 28 and 30 to form an assembly 31. The assembly 31 is consolidated by hot isostatic pressing using radially applied pressure. The separate pieces of metal matrix composite provide compliance to reduce breaking or buckling of the fibres, and the pieces of unreinforced metal matrix prevents damage spreading between laminations. The outer ring 30 is then machined to provide the rotor blades 16.

Fig. 1.

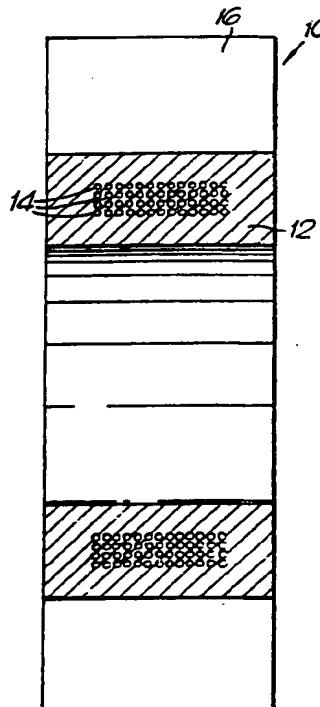
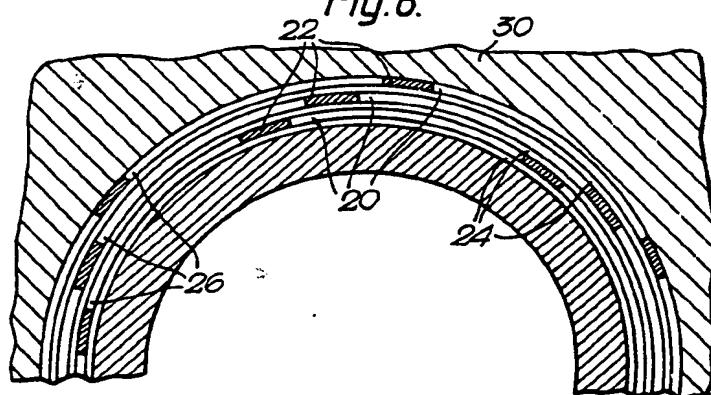


Fig. 6.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 247 492 A

1/3

Fig. 1.

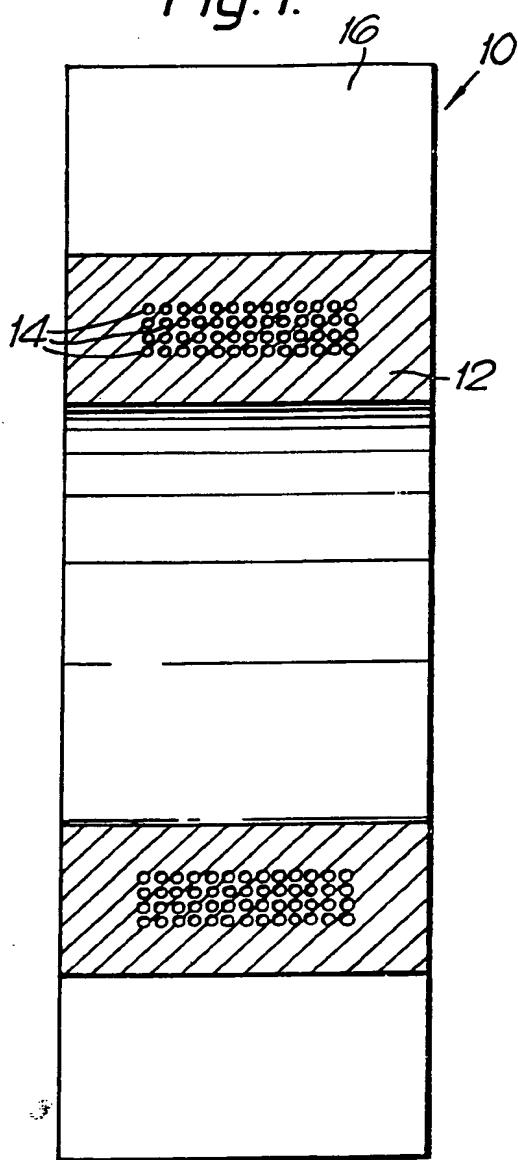


Fig. 3.

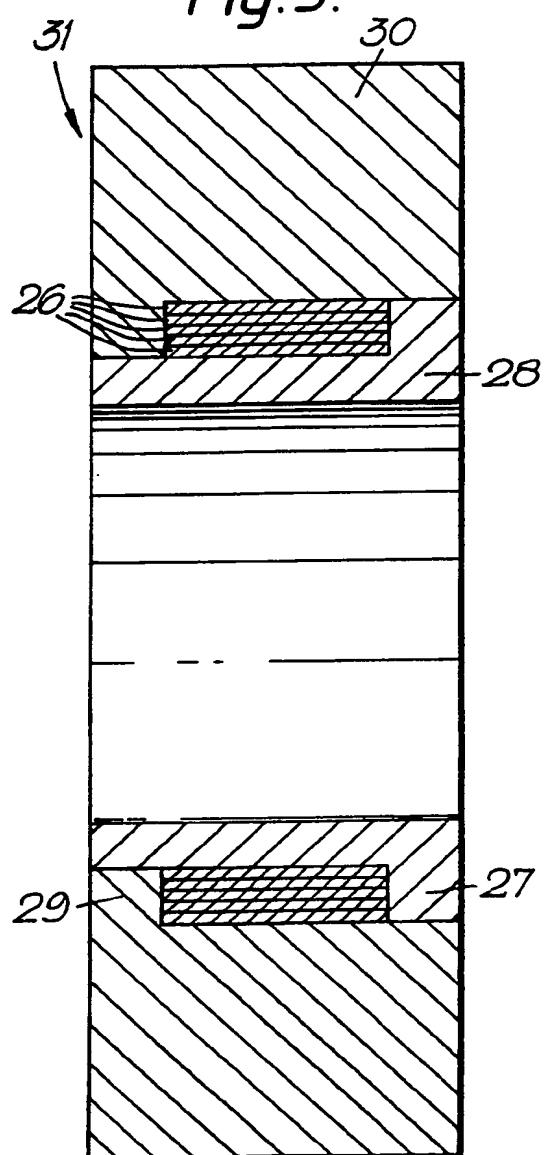
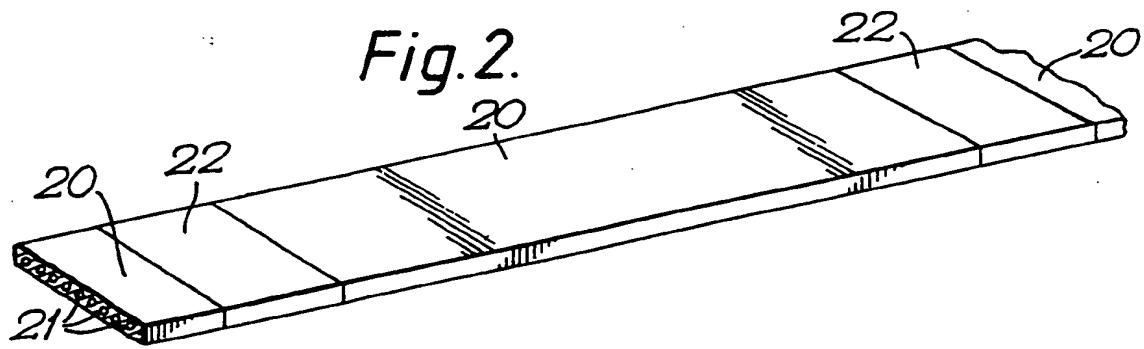
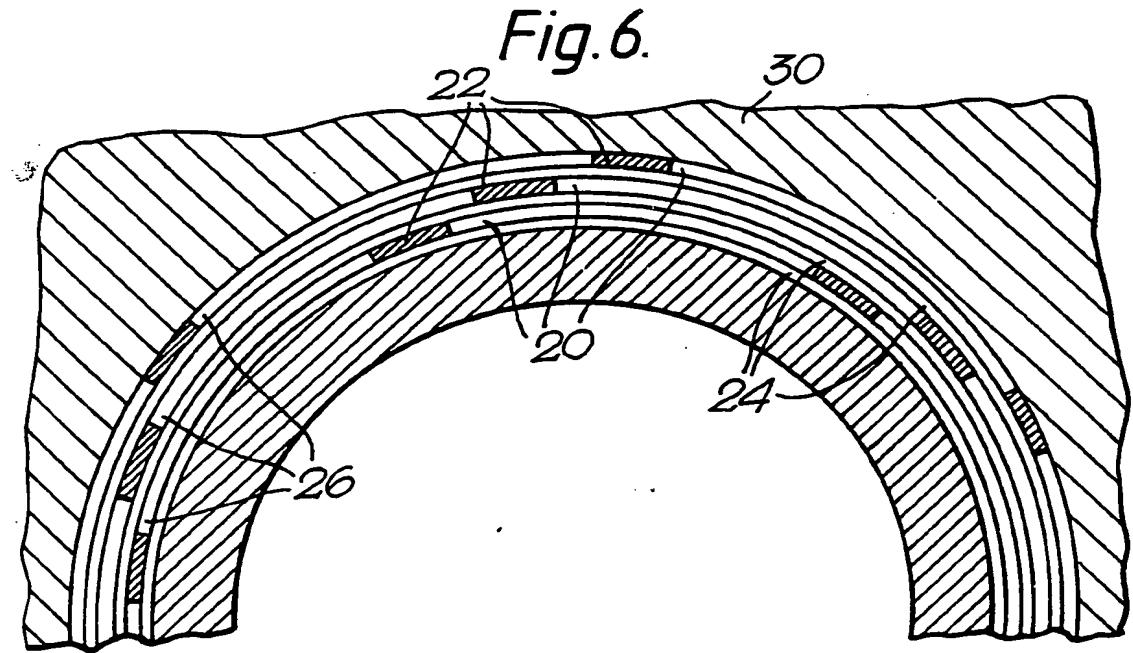
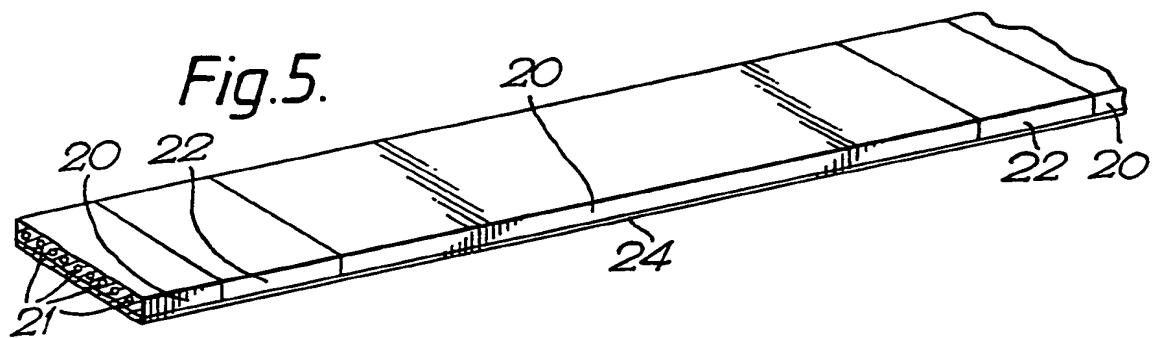
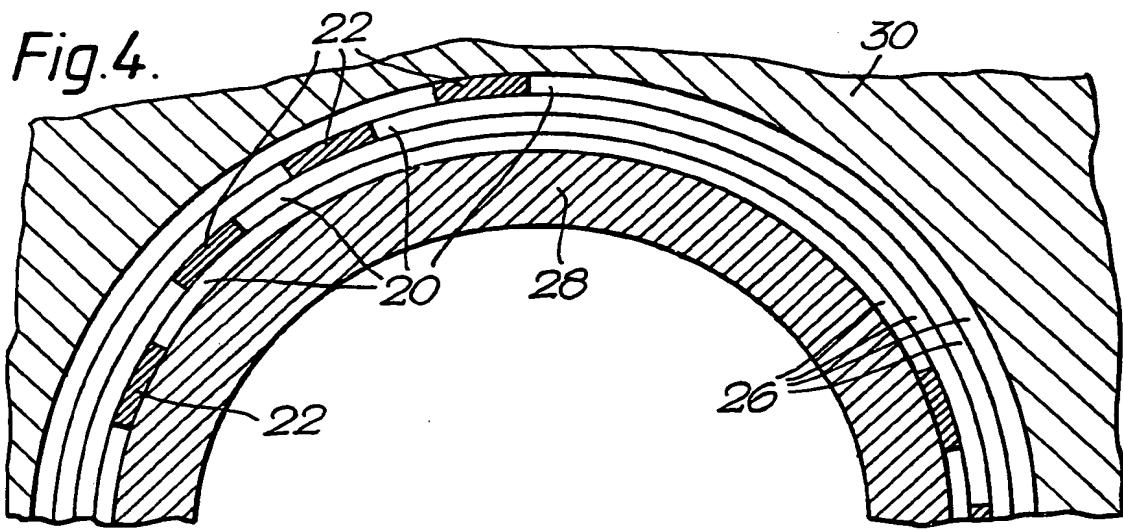


Fig. 2.





3/3

Fig.7.

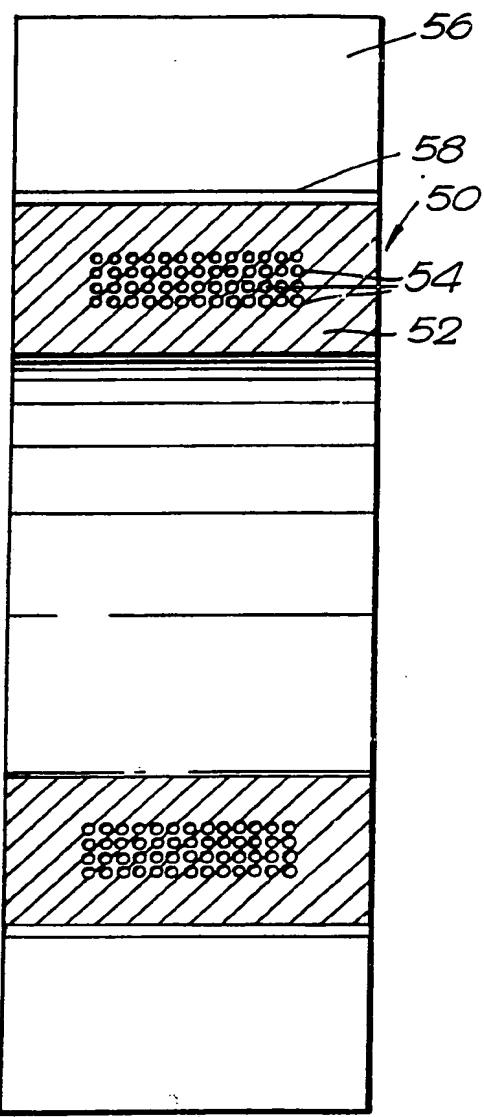
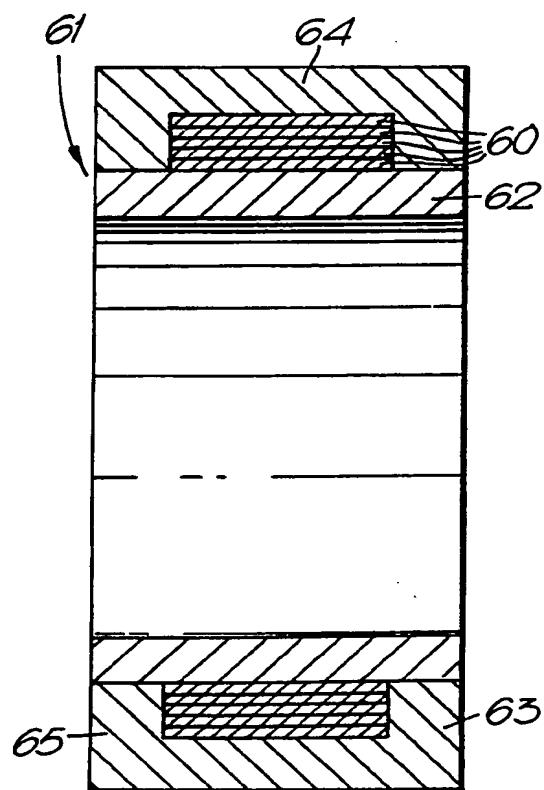


Fig.8.



A METHOD OF MAKING A FIBRE REINFORCED METAL COMPONENT

The present invention relates to a method of manufacturing fibre reinforced metal components, particularly fibre reinforced metal rings, cylinders and discs.

The ideal arrangement for a fibre reinforced metal ring, or disc, is to arrange the fibres circumferentially such that they extend continuously without breaks in a fully dense metal matrix. This is difficult to achieve because a certain amount of movement is required in practice to achieve good diffusion bonding, and density, between the layers of fibres. The fibres used to reinforce the metal matrix are ceramic, and ceramic fibres have very low extension to failure values, typically 1%. On consolidation using radial pressure from the inside surface of the ring the continuous ceramic fibres are placed under high tensile stress resulting in filament breakage and loss of structural integrity. On consolidation using radial pressure from the outer surface of the ring, the continuous ceramic fibres are buckled which reduces structural integrity. On consolidation using radial pressure from both the inside and outside surfaces of the ring, the continuous ceramic fibres either break under high tensile stress for the radially inner layers of ceramic fibres or buckle for the radially outer layers of ceramic fibres. This resulting fibre reinforced metal ring therefore contains many random fibre breaks and thus the fibre reinforced metal ring has unknown levels of mechanical properties.

In one known method of manufacturing a fibre reinforced metal ring, as disclosed in UK Patent Application No. GB2168032A, a filament is wound spirally in a plane with matrix material between the turns of the spiral. The spiral is positioned between discs of matrix material, and is then pressed axially to consolidate the ring structure. This method produces little or no breaking of the fibres, however it is a laborious method.

In a further known method of manufacturing a fibre reinforced metal ring, as disclosed in UK Patent Application No. GB2078338A, a metal matrix tape, which has reinforcing fibres, is wound onto a mandrel and then inserted into a metal shaft. The fibres are arranged generally axially of the shaft. The assembly is pressed to consolidate the ring structure. This method does not have the ideal arrangement of fibres for a ring.

Another known method of manufacturing a fibre reinforced metal ring, as disclosed in UK patent Application No. GB2198675A, a continuous helical tape of fibres and a continuous helical tape of metal foil are interleaved. The interleaved helical tapes of fibres and metal foil are pressed axially to consolidate the assembly. This method produced little or no breaking of the fibres.

The present invention seeks to provide a novel method of manufacturing fibre reinforced metal components.

Accordingly the present invention provides a method of manufacturing a fibre reinforced metal component comprising arranging at least one separate piece of metal matrix composite and at least one piece of unreinforced metal matrix alternately in adjacent abutting relationship to form at least one laminate, the at least one separate piece of metal matrix composite comprises a plurality of unidirectionally arranged fibres in a metal matrix, the at least one separate piece of metal matrix composite being arranged such that the fibres embedded in the metal matrix extend in the same directional sense, arranging the at least one laminate of at least one metal matrix composite piece and at least one piece of unreinforced metal matrix between a first metal member and a second metal member to form an assembly, consolidating the assembly to bond the first metal member, the at least one laminate of at least one metal matrix composite and the at least one piece of metal matrix and the second metal member to form a unitary composite component.

Preferably a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged to form at least one laminate.

Preferably the at least one separate piece of metal matrix composite and the at least one piece of unreinforced metal matrix are arranged in a ring, the first metal member and the second metal member are rings.

Preferably a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged in a spiral to form a plurality of laminates.

Alternately a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged in concentric rings to form a plurality of laminates.

The pieces of metal matrix composite may have equal lengths.

The second metal ring is preferably positioned radially outwardly of the at least one laminate of metal matrix composite.

At least one rotor blade may be welded onto the second metal ring by friction welding or electron beam welding.

Preferably the second metal ring is machined to form at least one rotor blade integral with the second metal ring.

Preferably the second metal member is electrochemically machined to form the at least one rotor blade.

The separate pieces of metal matrix composite and the pieces of unreinforced metal matrix may be secured to a continuous backing strip to allow the separate pieces of metal matrix composite and the pieces of unreinforced metal matrix to be wound into a spiral.

The backing strip may comprise unreinforced metal matrix.

Preferably the backing strip comprises a plastic or other suitable material which is subsequently removed.

The first metal member, the second metal member and the metal matrix composite may comprise titanium, titanium aluminide, an alloy of titanium or any suitable metal, alloy or intermetallic which is capable of being bonded.

The fibres may comprise silicon carbide, silicon nitride, boron, alumina or other suitable ceramic fibres.

Preferably the consolidating process comprises hot isostatic pressing.

The consolidating process may alternately comprise differential hot expansion of a first ring inside a suitable low expansion second ring.

The pieces of metal matrix composite and the pieces of metal matrix are preferably arranged on the inner surface of the second metal ring, the first metal ring is moved coaxially into the second metal ring.

The second metal ring preferably has a radially inwardly extending flange at one axial end to locate the pieces of metal matrix composite and the pieces of metal matrix axially.

The first metal ring preferably has a radially outwardly extending flange at one axial end to locate the pieces of metal matrix composite and the pieces of metal matrix axially.

The present invention will be more fully described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a longitudinal cross-sectional view through a bladed compressor rotor made according to the present invention.

Figure 2 is a perspective view of strips of unidirectional fibre reinforced metal matrix arranged alternately with inserts of unreinforced metal matrix.

Figure 3 is a longitudinal cross-sectional view through an assembly of strips of undirectional fibre reinforced metal matrix and inserts of unreinforced metal matrix positioned between inner and outer metal rings.

Figure 4 is an enlarged transverse cross-sectional view through the assembly in Figure 3.

Figure 5 is a perspective view of strips of unidirectional fibre reinforced metal matrix arranged alternately with inserts of unreinforced metal matrix on a backing strip.

Figure 6 is an alternative enlarged transverse cross-sectioned view through the assembly in Figure 3.

Figure 7 is a longitudinal cross-sectional view through an alternative bladed compressor rotor made according to the present invention.

Figure 8 is a longitudinal cross-sectional view through an assembly of strips of unidirectional fibre reinforced metal matrix and inserts of unreinforced metal matrix positioned between inner and outer metal rings.

A finished ceramic fibre reinforced metal rotor 10 with integral rotor blades is shown in Figure 1. The rotor comprises a metal ring 12 which includes a ring of circumferentially extending reinforcing ceramic fibres 14, which are fully diffusion bonded into the metal ring 12. A plurality of solid metal rotor blades 16, extend radially outwardly from and, are integral with the metal ring 12.

The ceramic fibre reinforced metal rotor 10 is manufactured using a conventional continuous strip containing a monolayer of unidirectional ceramic fibres embedded in a metal matrix. The continuous strip of unidirectional ceramic fibres in the metal matrix or metal matrix composite strip, is cut into a number of separate pieces of metal matrix composite. Each of the separate pieces of metal matrix composite is cut to a predetermined length dependent upon the diameter of the rotor and for other reasons which will be mentioned herein.

The separate pieces of metal matrix composite 20 are preferably arranged alternately with separate pieces of unreinforced metal matrix 22 in adjacent abutting relationship, as shown in Figure 2. The pieces of

unreinforced metal matrix also have predetermined lengths. The separate pieces of metal matrix composite 20 are arranged such that the ceramic fibres 21 in adjacent pieces extend in the same direction. The pieces of metal matrix composite 20 and the pieces of unreinforced metal matrix 22 are arranged in a spiral to form a ring which has a plurality of laminations 26, as shown in Figures 3 and 4, in which all the fibres extend circumferentially.

The lengths of the pieces of metal matrix composite 20 and the lengths of the pieces of unreinforced metal matrix 22 are selected to suite the diameter of the rotor, such that there is an optimum distribution of the unreinforced metal matrix pieces throughout the completed rotor to obtain a uniform distribution of strength throughout the circumference of the rotor. The distribution of unreinforced metal matrix pieces is such that they are not radially adjacent each other in adjacent laminations.

The laminations 26 of metal matrix composite pieces and unreinforced metal matrix pieces are arranged between an inner metal ring 28 and an outer metal ring 30 to form an assembly 31 as shown in Figure 3.

The pieces of metal matrix composite 20 and the pieces of unreinforced metal matrix 22 are arranged in a spiral by placing the pieces alternately adjacent each other in end to end relationship on the inner surface of the outer metal ring 30. The outer metal ring 30 has a radially inwardly extending flange 29 at one axial end which locates the pieces axially. When the pieces of metal matrix composite and pieces of unreinforced metal matrix have been arranged in laminations to the internal diameter of the flange 29, the inner metal ring 28 is pushed coaxially into the outer metal ring 30. The inner metal ring 28 has a radially outwardly extending flange 27 at one axial end which abuts the pieces at the opposite axial end to the flange 29 of the outer metal ring 30. The inner diameter of flange 29 is substantially the same

as the outer diameter of the inner metal ring 28 and the outer diameter of flange 27 is substantially the same as the inner diameter of the outer metal ring 30.

The assembly 31 is placed in a vacuum chamber which is subsequently evacuated, the flange 27 of the inner ring 28 is welded to the outer ring 30 and the flange 29 of the outer ring 30 is welded to the inner ring 28. Electron beam welding or other suitable welding processes may be used.

The assembly 31 is then consolidated using heat and pressure to form a fibre reinforced metal ring. The vacuum chamber is heated so as to heat the assembly 31 and a pressurising gas, for example argon, is introduced to apply pressure onto the assembly 31. The consolidation takes place using radial pressure on both the inside surface of the inner metal ring 28 and on the outside surface of the outer metal ring 30, and pressure is also applied on the axial surfaces of the rings. The application of heat and pressure to the assembly 31 is preferably by hot isostatic pressing.

The use of the plurality of separate pieces of metal matrix composite in the laminations provides the required degree of compliance in the assembly, to allow the ceramic fibres to move circumferentially without further breaking during the consolidation. The use of the plurality of separate pieces of unreinforced metal matrix between adjacent pieces of metal matrix composite allows the consolidation process to achieve full density and good diffusion bonding, and prevents fibres in a piece of metal matrix composite in an adjacent lamination becoming damaged due to the spreading of breakages. The incorporation of a piece of unreinforced metal matrix, i.e. a break in the ceramic fibres in a laminate is preferable to an area with several laminations each of which has broken ceramic fibres.

The outer metal ring 30 in Figure 3 is much greater in radial dimension than the inner metal ring 28, so that after the assembly has been consolidated, the outer metal

ring 30 is machined to produce a finished ceramic fibre reinforced metal rotor. The outer metal ring 30 may be machined to produce axially extending firtree, or dovetail, slots or may be machined to produce a circumferentially extending dovetail slot using conventional machining techniques to receive conventional compressor or turbine blades.

The outer metal ring 30 is much greater in radial dimension than the inner metal ring 28, so that after the assembly has been consolidated, the outer metal ring 30 may be machined, e.g. electrochemically machined, to produce the finished ceramic fibre reinforced metal rotor with integral blades as shown in Figure 1. The outer metal ring 30 is more massive than the inner metal ring 28, and so the assembly is consolidated more in a radially outward direction.

In Figure 5 the separate pieces of metal matrix composite 20, and the separate pieces of unreinforced metal matrix 22 are secured to a continuous backing strip 24 to allow the separate pieces of metal matrix composite 20 and unreinforced metal matrix 22 to be easily wound into a spiral. A ring formed from the backing strip 24, the pieces of metal matrix composite 20 and unreinforced metal matrix 22 is shown in Figure 6. The backing strip 24 is a thin strip of unreinforced metal matrix which is consolidated into the final component structure. Alternatively the backing strip 24 may be a plastic, or other suitable material which may be subsequently burnt off when the spiral is in place between the inner and outer metal rings.

The ceramic fibres have for example diameters of the order of 140 microns and the metal matrix composite pieces have a thickness of for example of 0.01 inch = 0.25 mm. When the laminates of metal matrix composite pieces are consolidated this gives a 35-45% volume fraction of ceramic fibres. The introduction of an unreinforced metal matrix backing strip reduces the volume fraction of

ceramic fibres in the consolidated structure, therefore it is necessary for the backing strip to be relatively thin to minimise the reduction in volume fraction of ceramic fibres.

The pieces of metal matrix composite and the pieces of unreinforced metal matrix may alternatively be arranged in concentric laminations to form a ring in which the fibres extend circumferentially. The laminations, may comprise a single piece of metal matrix composite and a single piece of unreinforced metal matrix, or they may comprise a plurality of pieces of metal matrix and a plurality of pieces of unreinforced metal matrix.

The consolidation of the assembly of inner metal ring, laminations of metal matrix composite pieces and unreinforced metal matrix pieces and the outer metal ring may be by using an extra inner ring, or cylinder, of high expansion coefficient material and an extra outer ring, or cylinder, of low expansion coefficient material. The assembly is placed into a vacuum chamber, which is subsequently evacuated. The assembly is then consolidated using heat which causes the inner ring to expand more than the outer ring and thus consolidate the assembly to form a fibre reinforced metal ring. The edges of the inner and outer metal rings of the composite assembly may be electron beam welded together.

A further finished ceramic fibre reinforced metal rotor 50 with rotor blades is shown in Figure 7. The rotor comprises a metal ring 52 which includes a ring of circumferentially extending reinforcing ceramic fibres 54, which are fully diffusion bonded into the metal ring 52. A plurality of solid metal rotor blades 56, extend radially outwardly from the metal ring 52. The rotor blades 56 are secured to the metal ring 52 by welds 58.

The pieces of metal matrix composite 20 and the pieces of unreinforced metal matrix 22 are arranged in a spiral by placing the pieces alternately adjacent each other in end to end relationship on the inner surface of

the outer metal ring 64. The outer metal ring 64 has two radially inwardly extending flanges 63 and 65 at opposite axial ends which locate the pieces axially. When the pieces of metal matrix composite and pieces of unreinforced metal matrix have been arranged in laminations to the internal diameter of the flanges 63 and 65, the inner metal ring 62 is pushed coaxially into the outer metal ring 64.

The bladed rotor 50 is produced in a similar manner to that in Figure 1, but the outer metal ring 64 has a much smaller radial dimension in Figure 8 than that in Figure 3. Therefore after the assembly has been consolidated, instead of electrochemically machining the outer metal ring 64 to produce the integral rotor blades, a plurality of solid metal rotor blades are electron beam welded or friction welded onto the outer metal ring 64.

The pieces of metal matrix composite and the pieces of unreinforced metal matrix may be arranged between two radially outwardly extending flanges on the inner metal ring, and the outer metal ring may be pushed coaxially onto the inner metal ring. Other suitable methods of locating the pieces between the inner and outer metal rings may be used.

The inner and outer metal rings may be titanium, titanium aluminide, any titanium alloy or any other metal, intermetallic or alloy which is capable of being bonded together. The metal matrix composite may be a matrix of titanium, aluminium, nickel or magnesium metal or alloy. The metal matrix composite may be reinforced with silicon carbide, silicon nitride, boron, alumina or other suitable ceramic fibres.

The consolidated fibre reinforced metal ring may be a finished or semi-finished component. The consolidated fibre reinforced metal ring may be a finished cylinder, casing or shaft. The consolidated fibre reinforced metal ring may be a semi-finished rotor.

**Claims:-**

1. A method of manufacturing a fibre reinforced metal component comprising arranging at least one separate piece of metal matrix composite and at least one piece of unreinforced metal matrix alternately in adjacent abutting relationship to form at least one laminate, the at least one separate piece of metal matrix composite comprises a plurality of unidirectionally arranged fibres in a metal matrix, the at least one separate piece of metal matrix composite being arranged such that the fibres embedded in the metal matrix extend in the same directional sense, arranging the at least one laminate of at least one metal matrix composite piece and at least one piece of unreinforced metal matrix between a first metal member and a second metal member to form an assembly, consolidating the assembly to bond the first metal member, the at least one laminate of at least one metal matrix composite and the at least one piece of metal matrix and the second metal member to form a unitary composite component.
2. A method as claimed in claim 1 in which a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged to form at least one laminate.
3. A method as claimed in claim 1 or claim 2 in which the at least one separate piece of metal matrix composite and the at least one piece of unreinforced metal matrix are arranged in a ring, the first metal member and the second metal member are rings.
4. A method as claimed in claim 3 in which a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged in a spiral to form a plurality of laminates.
5. A method as claimed in claim 3 in which a plurality of separate pieces of metal matrix composite and a plurality of pieces of unreinforced metal matrix are arranged in concentric rings to form a plurality of laminates.

6. A method as claimed in any of claims 1, 2, 3, 4 or 5 in which the pieces of metal matrix composite have equal lengths.

7. A method as claimed in any of claims 3, 4 or 5 in which the second metal ring is positioned radially outwardly of the at least one laminate of metal matrix composite.

8. A method as claimed in claim 7 comprising welding at least one rotor blade onto the second metal ring.

9. A method as claimed in claim 8 in which the at least one rotor blade is welded onto the second metal ring by friction welding or electron beam welding.

10. A method as claimed in claim 7 comprising machining the second metal ring to form at least one rotor blade integral with the second metal ring.

11. A method as claimed in claim 10 in which the second metal member is electrochemically machined to form the at least one rotor blade.

12. A method as claimed in claim 3 in which the separate pieces of metal matrix composite and the pieces of unreinforced metal matrix are secured to a continuous backing strip to allow the separate pieces of metal matrix composite and the pieces of unreinforced metal matrix to be wound into a spiral.

13. A method as claimed in claim 12 in which the backing strip comprises unreinforced metal matrix.

14. A method as claimed in claim 12 in which the backing strip comprises a plastic or other suitable material which is subsequently removed.

15. A method as claimed in any of claims 1 to 14 in which the first metal member and the second metal member comprise titanium, titanium aluminide, an alloy of titanium or any suitable metal, alloy or intermetallic which is capable of being bonded.

16. A method as claimed in any of claims 1 to 15 in which the metal matrix composite comprises a matrix of titanium, titanium aluminide, an alloy of titanium or any suitable

metal, alloy or intermetallic which is capable of being bonded.

17. A method as claimed in any of claims 1 to 16 in which the fibres comprise silicon carbide, silicon nitride, boron, alumina or other suitable ceramic fibres.

18. A method as claimed in any of claims 1 to 17 in which the consolidating process comprises hot isostatic pressing.

19. A method as claimed in any of claims 1 to 17 in which the consolidating process comprises differential hot expansion of a first ring inside a suitable low expansion second ring.

20. A method as claimed in claim 7 in which the pieces of metal matrix composite and the pieces of metal matrix are arranged on the inner surface of the second metal ring, the first metal ring is moved coaxially into the second metal ring.

21. A method as claimed in claim 20 in which the second metal ring has a radially inwardly extending flange at one axial end to locate the pieces of metal matrix composite and the pieces of metal matrix axially.

22. A method as claimed in claim 21 in which the first metal ring has a radially outwardly extending flange at one axial end to locate the pieces of metal matrix composite and the pieces of metal matrix axially.

23. A bladed compressor rotor or a bladed turbine rotor as made by the methods of claims 8, 9, 10 or 11.

24. A casing or a shaft as made by the methods of claim 2, 3, 4 or 5.

25. A method of manufacturing a fibre reinforced metal component substantially as hereinbefore described with reference to Figures 1 to 4.

26. A method of manufacturing a fibre reinforced metal component substantially as hereinbefore described with reference to Figures 5 and 6.

27. A method of manufacturing a fibre reinforced metal component substantially as hereinbefore described with reference to Figures 7 and 8.